UNIVERSITY OF CALIFORNIA—COLLEGE OF AGRICULTURE.
AGRICULTURAL EXPERIMENT STATION,
E. W. HILGARD, Director.

NATURE, VALUE, AND UTILIZATION OF ALKALI LANDS.

ALKALI SPOTS BEFORE RECLAMATION. TULARE EXPERIMENT SUBSTATION.

BY
E. W. HILGARD.

BULLETIN No. 128.
(March, 1900.)

SACRAMENTO:
A. J. JOHNSTON, : : : : : SUPERINTENDENT STATE PRINTING.
1900.

TABLE OF CONTENTS.

Page.

Occurrence and Characteristics of Alkali Soils 3
How Plants are Injured by Alkali 5
Effects of Irrigation 5
Determination of the Distribution of the Alkali Salts 6
Composition of Alkali Salts; summary of conclusions 13
Utilization and Reclamation of Alkali Lands 14
Counteracting Evaporation; Diluting the Alkali Salts; Chemical Remedies; Stable Manure and Other Fertilizers 14–18
Removing the Salts from the Soil 19
Will it Pay to Reclaim Alkali Lands 20
Crops Suitable for Alkali Lands 22
Amount of Salts Compatible with Ordinary Crops 24
Grasses; Legumes; Weeds; Root Crops; Textile Plants; Grapevines; Citrus Trees; Deciduous Orchard Trees; Timber and Shade Trees 24–29
Irrigation with Saline Waters 30
Limits of Saline Contents 31
Reclaimable and Irreclaimable Alkali Lands as distinguished by their Natural Vegetation 35
Tussock Grass; Greasewood; Dwarf Samphire; Bushy Samphire; Saltwort; Alkali-Heath; Cressa 37–44
Relative Tolerance of the Different Species 44
Total Salt Indicators; Salsoda Indicators; Neutral Salt Indicators 46

ILLUSTRATIONS.

Alkali Spots before Reclamation ..... Title-page.
Diagrams showing Distribution of Alkali Salts 7, 8, 10, 11
Wheat on Soil crusted with White Alkali 17
Alkali Lands in San Joaquin Valley 21
Orange Trees irrigated with Artesian Water 32
Orange Trees irrigated with Alkali Water of Elsinore Lake 33
Alkali Grasses: Tussock Grass; Greasewood; Dwarf Samphire; Bushy Samphire; Saltwort; Alkali-Heath; Cressa 37–44

THE NATURE, VALUE, AND UTILIZATION OF ALKALI LANDS.*

By E. W. Hilgard.

[The continuous and pressing demand for information on alkali lands and their utilization having exhausted the printed matter heretofore published by this Station on the subject, it seems best to publish a brief general summary of the results of our investigations, made during the past twenty years, for the use of farmers and land owners and the general public. Those desiring more detailed information will find the record, so far as printed, in the reports of the Station from 1879 to 1898.]

Occurrence and Characteristics of Alkali Soils.

Alkali lands must be pointedly distinguished from the salty lands of sea margins or marshes, from which they differ in both their origin and essential nature. Marsh lands derive their salts from sea water that occasionally overflows them, and the salts which impregnate them are essentially "sea salts"; that is, common salt, together with bittern, epsom salt, etc. Very little of what would be useful to vegetation or desirable as a fertilizer is contained in the salts impregnating such soils; and they are by no means always intrinsically rich in plant food, but vary greatly in this respect.

Alkali lands bear no definite relation to the sea; they are mostly remote from it or from any former sea bed, so that they have sometimes been designated as "terrestrial salt lands." Their existence is usually definitely traceable to climatic conditions alone. They are the natural result of a light rainfall, insufficient to leach out of the land the salts that always form in it by the progressive weathering of the rock powder of which all soils largely consist. Where the rainfall is abundant, that portion of the salts corresponding to "sea salts" is leached out into the bottom water, and with this passes through springs and rivulets into the country drainage, to be finally carried to the ocean. Another portion of the salts formed by weathering, however, is partially or wholly retained by the soil; it is that portion chiefly useful as plant-food.

It follows that when, in consequence of insufficient rainfall, all or most of the salts are retained in the soil, they will contain not only

* Revision of a paper published in the Yearbook of the U. S. Department of Agriculture for 1895, with abstracts from reports and records of the California Experiment Station.

the ingredients of sea water, but also those useful to plants. In rainy climates a large portion even of the latter is leached out and carried away. In extremely arid climates their entire mass remains in the soils; and, being largely soluble in water, evaporation during the dry season brings them to the surface, where they may accumulate to such an extent as to render the growth of ordinary useful vegetation impossible; as is seen in "alkali spots," and sometimes in extensive tracts of "alkali desert."

In looking over a rainfall map of the globe we see that a very considerable portion of the earth's surface has deficient rainfall, the latter term being commonly meant to imply any annual average less than 20 inches (500 millimeters). The arid region thus defined includes, in North America, most of the country lying west of the one hundredth meridian up to the Cascade Mountains, and northward beyond the line of the United States; southward, it reaches far into Mexico, including especially the Mexican plateau. In South America it includes nearly all the Pacific Slope (Peru and Chile) south to Araucania; and eastward of the Andes, the greater portion of the plains of western Brazil and Argentina. In Europe only a small portion of the Mediterranean border is included; but the entire African coast belt opposite, with the Saharan and Libyan deserts, Egypt, and Arabia are included therein, as well as a considerable portion of South Africa. In Asia, Asia Minor, Syria (with Palestine), Mesopotamia, Persia, and northwestern India up to the Ganges, and northward, the great plains or steppes of central Asia eastward to Mongolia and western China, fall into the same category; as does also a large portion of the Australian continent.

Over these vast areas alkali lands occur to a greater or less extent, the exceptions being the mountain regions and adjacent lands on the side exposed to prevailing oceanic winds. It will therefore be seen that the problem of the utilization of alkali lands for agriculture is not of local interest only, but is of world-wide importance. It will also be noted that many of the countries referred to are those in which the most ancient civilizations have existed in the past, but which at present, with few exceptions, are occupied by semicivilized people only. It is doubtless from this cause that the nature of alkali lands has until now been so little understood that even their essential distinctness from the sea-border lands has been but lately recognized in full. Moreover, the great intrinsic fertility of these lands has been very little appreciated, their repellent aspect causing them to be generally considered as waste lands.

This aspect is essentially due to their natural vegetation being in most cases confined to plants useless to man, commonly designated as "saline vegetation," of which but little is usually relished by

cattle. Notable exceptions to this rule occur in Australia and Africa, where the "saltbushes" of the former and the "karroo" vegetation of the latter form valuable pasture grounds. Apart from these, however, the efforts to find for these lands while in their natural condition, culture plants generally acceptable, or at least profitable, outside of forage crops, have not been very successful.

How Plants Are Injured by Alkali.

When we examine plants that have been injured by alkali, we will usually find that the damage has been done near the base of the trunk, or root crown; rarely at any considerable depth in the soil itself. In the case of green herbaceous stems, the bark is found to have turned to a brownish tinge for half an inch or more, so as to be soft and easily peeled off. In the case of trees, the rough bark is found to be of a dark, almost black, tint, and the green layer underneath has, as in the case of an herbaceous stem, been turned brown to a greater or less extent. In either case the plant has been practically "girdled," the effect being aggravated by the diseased sap poisoning, more or less, the whole stem and roots. The plant may not die, but it will be quite certain to become unprofitable to the grower.

It is mainly in the case of land very heavily charged with common salt, as in the marshes bordering the sea or salt lakes, that injury arises from the direct effects of the salty soil-water upon the feeding roots themselves. In a few cases the gradual rise of salt water from below, in consequence of defective drainage, has seriously injured, and even destroyed, old orange orchards.

The fact that in cultivated land the injury is usually found to occur near the surface of the soil, concurrently with the well-known fact that the maximum accumulation of salts at the surface is always found near the end of the dry season, indicates clearly that this accumulation is due to evaporation at the surface. The latter is often found covered with a crust consisting of earth cemented by the crystallized salts, and later in the season with a layer of whitish dust resulting from the drying-out of the crust first formed. It is this dust which becomes so annoying to the inhabitants and travelers in alkali regions, when high winds prevail, irritating the eyes and nostrils and parching the lips.

Effects of Irrigation.

One of the most annoying and discouraging features of the cultivation of lands in alkali regions is that, although in their natural condition they may show but little alkali on their surface, and that mostly in limited spots, usually somewhat depressed below the general surface, these spots are found to enlarge rapidly as irrigation is practiced; and since alkali salts are the symptoms and result of insufficient

rainfall, irrigation is a necessary condition of agriculture wherever they prevail. Under irrigation, neighboring spots will oftentimes merge together into one large one, and at times the entire area, once highly productive and perhaps covered with valuable plantations of trees or vines, will become incapable of supporting useful growth. This annoying phenomenon is popularly known as "the rise of the alkali" in the western United States, but is equally well known in India and other irrigation regions.

The process by which the salts rise to the surface is the same as that by which oil rises in a wick. The soil being impregnated with a solution of the alkali salts, and acting like the wick, the salts naturally remain behind on the surface as the water evaporates, the process only stopping when the moisture in the soil is exhausted. We thus not infrequently find that after an unusually heavy rainfall there follows a heavier accumulation of alkali salts at the surface, while a light shower produces no perceptible permanent effect. We are thus taught that, within certain limits, the more water evaporates during the season the heavier will be the rise of the alkali; provided that the water is not so abundant as to leach the salts through the soil and subsoil into the subdrainage.

Worst of all, however, is the effect of irrigation ditches laid in sandy lands (such as are naturally predominant in arid regions), without proper provision against seepage. The ditch water then gradually fills up the entire substrata so far as they are permeable, and the water-table rises from below until it reaches nearly to the ditch level; shallowing the subsoil, drowning out the deep roots of all vegetation, and bringing close to the surface the entire mass of alkali salts previously diffused through many feet of substrata. If this condition is allowed to continue for some time, alkali salts originally "white" will by a chemical change become "black" by the formation of carbonate of soda from the glauber salt; greatly aggravating the injury to vegetation. More than this, if such swamping is allowed to continue for a number of years, the land may be permanently injured; so that even after the alkali is removed, the soil remains inert and unthrifty for years.

Determination of the Distribution of the Alkali Salts.

In order to gain a basis for the possible means of reclaiming alkali lands, it is evidently necessary to determine by direct observation the manner in which the salts are distributed in the soils under different conditions. This can be done by sampling the soil at short intervals of depth, and leaching out and analyzing each sample separately. While this involves a great deal of work, it is manifestly the only conclusive method.

A series of such investigations has been first carried out by the California Experiment Station during the years 1894 and 1895, with samples

taken in or near the substations near Tulare and Chino, Cal., with the results as given below. It should be understood that the alkali in the Tulare region is mostly of the "black" kind, that is, consisting largely of carbonate of soda, which dissolves the humus of the soil and thus gives rise to dark-colored spots and water-puddles. The soil is a rather sandy, gray loam (see Report California Experiment Station, 1889). On the Chino tract, on the contrary, the soil is a close-grained, rather heavy loam, naturally subirrigated; the salts are likewise mostly "black," the sodium carbonate being about one third of the whole.

Fig. 1 represents the condition of the salts in an "alkali spot" as found at the end of the dry season at the Tulare substation. The soil was sampled to the depth of 2 feet, at intervals of 3 inches each. The depths are entered in the vertical line to the left; the percentages of the total salts and of each of the principal ingredients are entered in decimal fractions of 1 per cent on horizontal lines running to the right, as indicated on the top line of the plate. Broken lines connecting the data in each case facilitate the understanding of the results. It is thus easy to see that at this time almost the entire mass of the salts was accumulated within the first six inches from the surface, while lower down the soil contained so little that few culture plants would be hurt by them.

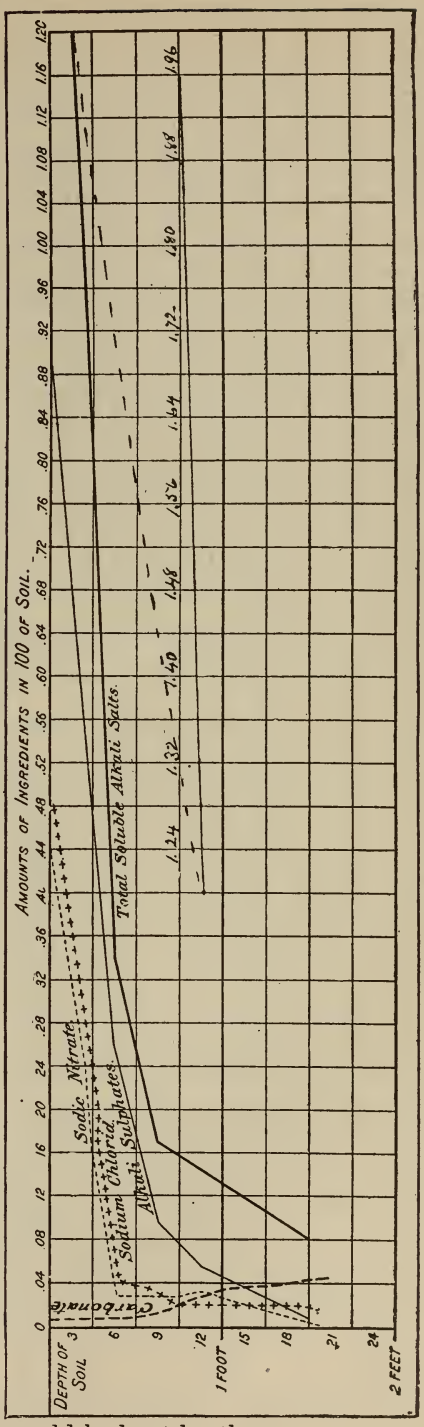

Fig. 1. Diagram showing amount and composition of alkali salts at various depths in partially reclaimed sandy alkali land, on which barley grew 4 feet high. Taken September, 1894. Tulare Experiment Substation, California.

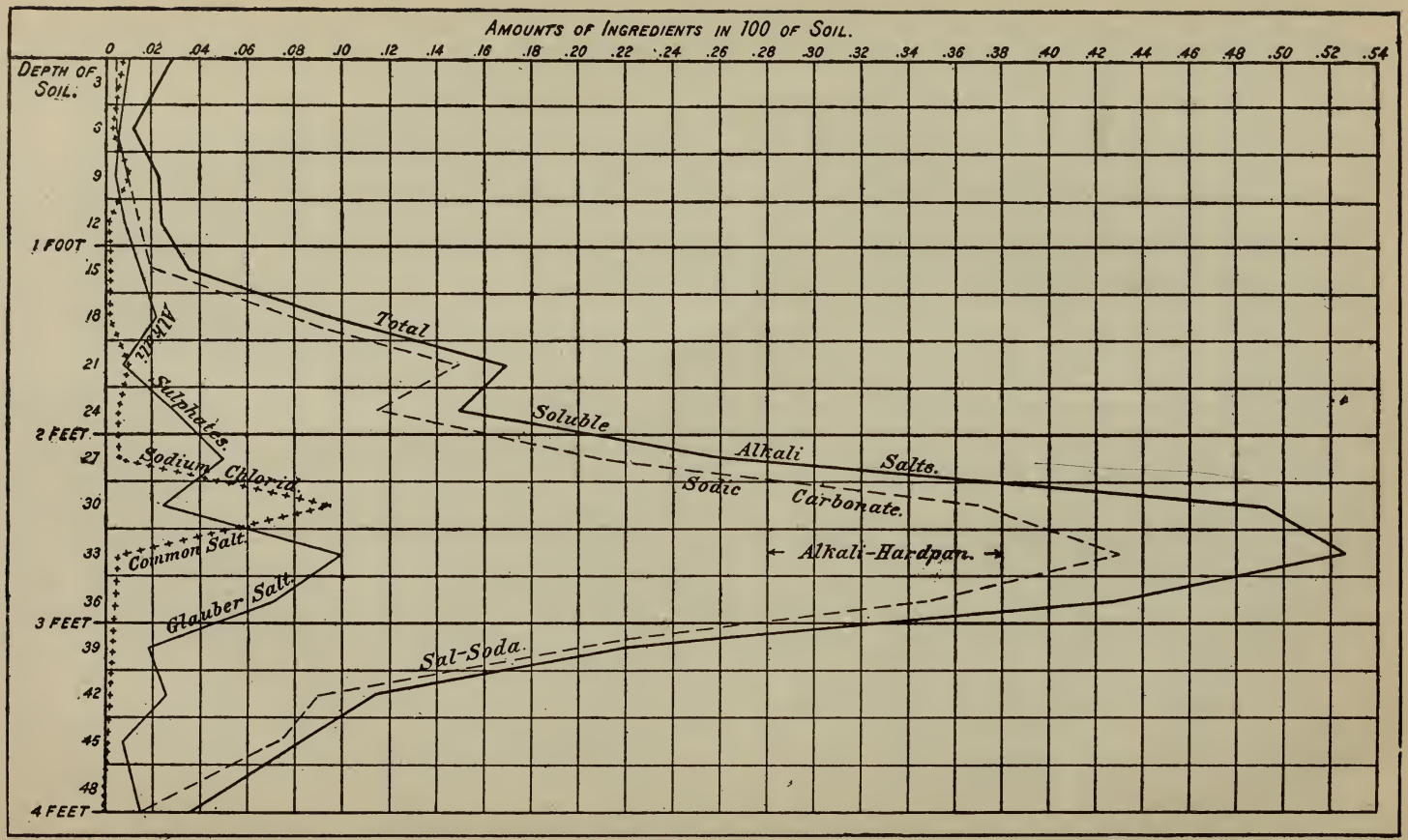

FIG. 2. Diagram showing amounts and composition of alkali salts at various depths in black-alkali land, unirrigated. Taken March, 1895. Tulare Exp. Substation.

Fig. 2 represents similarly the state of things in a natural soil alongside of the alkali spot, but in which the native vegetation of brilliant flowers develops annually without any hindrance from alkali. Samples were taken from this spot in March, near the end of the wet, and in September, near the end of the dry, season, and each series fully analyzed. There was scarcely a noticeable difference in the results obtained. It is seen in the figure that down to the depth of 15 inches there was practically no alkali found (0.035%),and it was within these 15 inches of soil that the native plants mostly had their roots and developed their annual growth. But from that level downward the alkali rapidly increased, and reached a maximum (0.529%) at about 33 inches, decreasing rapidly thence until, at the end of the fourth foot in depth, there was no more alkali than within the first foot from the surface. In other words, the bulk of the salts had accumulated at the greatest depth to which the annual rainfall (7 inches) ever reaches, forming there a sheet of tough, intractable clay hardpan. The shallow-rooted native plants germinated their seeds freely on the alkali-free surface, their roots kept above the strongly charged subsoil, and through them and the stems and foliage all the soil moisture was evaporated by the time the plants died. Thus no alkali was brought up from below by evaporation. The seeds shed would remain uninjured, and would again germinate the coming season.

It is thus that the luxuriant vegetation of the San Joaquin plains, dotted with occasional alkali spots, is maintained, the spots themselves being almost always depressions in which the rain water may gather, and where, in consequence of the increased evaporation, the noxious salts have risen to the surface and render impossible all but the most resistant saline growth; particularly when, in consequence of maceration and fermentation in the soil, the formation of carbonate of soda (black alkali) has caused the surface to sink and become almost water-tight.

After several years' cultivation with irrigation on the same land as in the last figure, a crop of barley 4 feet high was grown on the land. Investigation proved that here the condition of the soil was intermediate between the two preceding figures. The irrigation water had dissolved the alkali of the subsoil, and the abundant evaporation had brought it nearer the surface; but the shading by the barley crop and the evaporation of the moisture through its roots and leaves had prevented the salts from reaching the surface in such amounts as to injure the crop, although the tendency to rise was clearly shown.

Ten feet from this spot was bare alkali ground on which barley had refused to grow. Its examination proved it to contain a somewhat larger proportion (one-fifth more) of alkali salts, and in these a larger relative proportion of carbonate of soda (salsoda). Thus the seed was mostly destroyed before germination, and of the few seedlings none

lived beyond the fourth leaf. On the ground represented by Fig. 1, previous treatment with gypsum had so far diminished the salsoda that the grain germinated freely, and a very good crop of barley was harvested there without irrigation. The same season, grain crops were almost a failure on alkali-free land in the same region.

In connection with this result it should be noted as a general fact

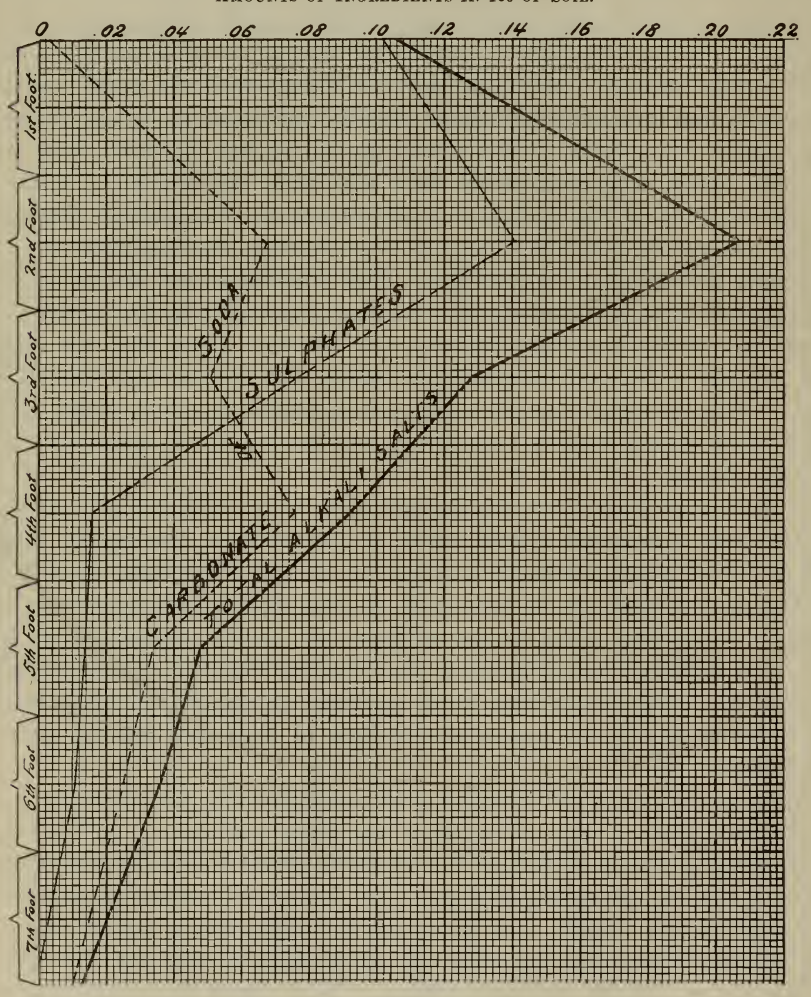

Fig. 3. Distribution of alkali salts in sandy land.

that *alkali lands always retain a certain amount of moisture* perceptible to the hand during the dry season, and that *this moisture can be utilized by crops;* so that at times when crops fail on nonalkaline land, good ones are obtained where a slight taint of alkali exists in the soil. Striking examples of this fact occur in the Spokane country within the great bend of the Columbia River, in the State of Washington; and the

same is illustrated by the luxuriant growth of weeds on the margin of alkali spots, just beyond the limit of corrosive injury. Actual determination showed that while a sample of alkali soil containing .54 per cent of salts absorbed 12.3 per cent of moisture from moist air, the same soil when leached absorbed only 2.5 per cent—a figure corresponding to that of sandy upland loams. Investigation at the Tulare substation during the dry season of 1898 also showed the presence of 15 and 16 per cent of water, respectively, in strong "white" and "black" alkali soils, while in adjoining light alkali soils there was but 10 per cent.

In *very* sandy lands, and particularly when the alkali is "white" only, the tendency to accumulation near the surface is much less, even under irrigation. In the natural condition the salts are in such cases

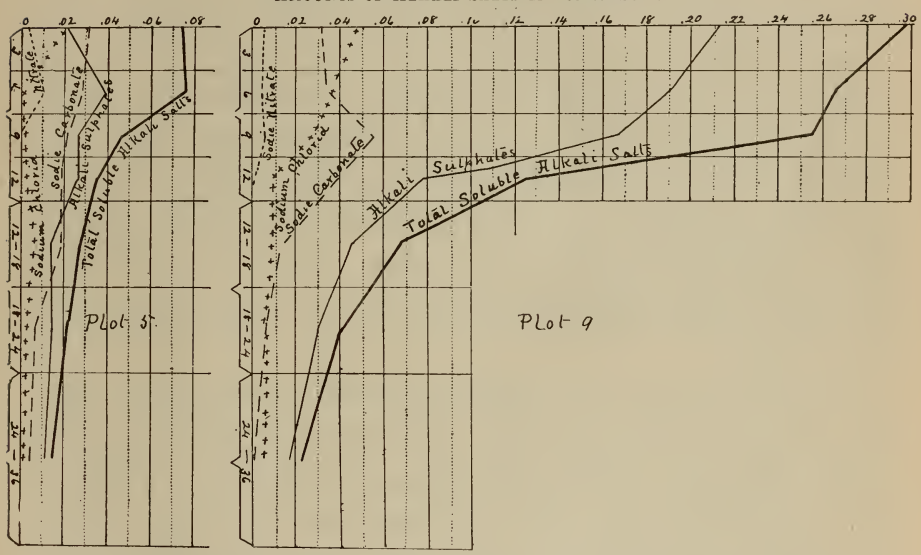

Fig. 4. Distribution of alkali salts in close-textured soil of the ten-acre tract, near Chino, Cal.

often found quite evenly distributed through soil columns of four feet, and even more. This is an additional cause of the lesser injuriousness of "white alkali."

Fig. 3 shows the distribution of the salts as found in a very sandy area on the Tulare substation grounds. It should be noted that here, while the general figure representing the distribution is very similar to that showing the same in a close soil (see Fig. 4) the salts reach down to over 6 feet, and are at their maximum 18 inches from, instead of *at* the surface.

The mode of distribution of alkali salts in the heavier, close-grained soil of the Chino tract is illustrated in Fig. 4. As has been mentioned, this land is permanently moist, from a water-table ranging from 5 to 7

feet below the surface in ordinary years. There is therefore no opportunity for the formation of "alkali hardpan" as in the case of the Tulare soil; the salts always remain rather near the surface, viz, within 12 to 18 inches. But being in much smaller average amounts than at Tulare (an average of about 5,300 pounds per acre), quite a copious natural vegetation of grasses, sunflowers, and "yerba mansa" covered the whole surface, save in a few low spots.

A similar mode of distribution of the salts is found in the more clayey "black adobe" lands of the Great Valley of California. The scanty rains cannot penetrate these soils to any great depth, so that evaporation will soon bring the salts carried by them back to within a short distance of the surface. Their accumulation there is frequently indicated by the entire absence of any but the most resistant alkali weeds, even though the total of salts in the land may not be very great.

While the phenomena of alkali lands as outlined above undoubtedly represent the vastly predominant conditions on extensive level lands, yet there are exceptions due to surface conformation, and to the local existence of sources of alkali salts outside of the soil itself. Such is the case where salts ooze out of strata cropping out on hillsides, as is the case at some points in the San Joaquin Valley in California, and in parts of Colorado, Wyoming, and Montana. In such cases the alkali salts may be most apparent near the foot of the hills, and in light, well-drained valley lands may disappear altogether before reaching the valley-trough.

On the other hand, it not infrequently happens that in sloping valleys or basins, where the central (lowest) portion receives the salts leached out of the adjacent hills and valley slopes in consequence of slow subdrainage, we find belts of greater or less width in which the alkali impregnation may reach to the depth of 10 or 12 feet, usually within more or less definite layers of calcareous hardpan, likewise the outcome of the leaching of the valley slopes. Such areas, however, are usually quite limited, and are, of course, scarcely reclaimable without excessive expenditure, the more as they are often underlaid by saline bottom water. In these cases the predominant saline ingredient is usually common salt, as might be expected, and as is exemplified on a large scale in the Great Salt Lake of Utah, and in the ocean itself.

In many cases, in California and elsewhere, the over-irrigation of bench or slope lands has caused, first the lower slopes, and then the bottom lands of streams and rivers, to be overrun with alkali salts, although before irrigation was practiced these lands were exempt from them. In some portions of the San Joaquin Valley this trouble has become most serious, fertile lands long under successful cultivation being rendered useless by thousands of acres, unless an expensive system of underdrainage were resorted to. Even this remedy is largely

inapplicable in the absence of legislation providing for right-of-way for drainage as well as for irrigation; but any such legislation should, at the same time, provide a remedy for the leakage of ditch-water, which is the original cause of the injury.

Composition of Alkali Salts.

Broadly speaking, it may be said that, the world over, alkali salts consist of three chief ingredients, namely, *common salt*, *glauber salt* (sulphate of soda), and *salsoda* or *carbonate of soda*. The latter causes what is popularly known as "black alkali," from the black spots or puddles seen on the surface of lands tainted with it, owing to the dissolution of the soil humus; while the other salts, often together with epsom salt, constitute "white alkali," which is known to be very much milder in its effect on plants than the black. In most cases all three are present, and all may be considered as practically valueless or noxious to plant growth. With them, however, there are almost always associated, in varying amounts, sulphate of potash, phosphate of soda, and nitrate of soda, representing the three elements—potassium, phosphorus, and nitrogen—upon the presence of which in the soil, in available form, the welfare of our crops so essentially depends, and which we aim to supply in fertilizers. The potash salt is usually present to the extent of from 5 to 20 per cent of the total salts; phosphate, from a fraction to as much as 4 per cent; the nitrate, from a fraction to as much as 20 per cent. In black alkali the nitrate is usually low, the phosphate high; in the white, the reverse is true.

It is thus clear that if we were to make a rule of reclaiming alkali lands by leaching out the salts with abundance of irrigation water, we would get rid not only of the noxious salts, but also of those ingredients upon which productiveness primarily depends, and for which we pay heavily in fertilizers. This is evidently to be avoided, if possible.

Summing up the conclusions from the foregoing observations and considerations we find that—

(1) The amount of soluble salts in alkali soils is usually limited; they are not ordinarily supplied in indefinite quantities from the bottom water below. These salts have essentially been formed by weathering, in the soil layer itself.

(2) The salts ordinarily move up and down within the upper 4 or 5 feet of the soil and subsoil, following the movement of the moisture; descending in the rainy season to the limit of the annual moistening as a maximum, and then reascending or not according as surface evaporation may demand. At the end of the dry season, in untilled irrigated land, practically the entire mass of salts may be within 6 or 8 inches of the surface.

(3) The injury to vegetation is caused mainly, sometimes wholly, within a few inches of the surface, by the corrosion of the bark, usually near the root crown. This corrosion is strongest when carbonate of soda (salsoda) forms a large proportion of the salts; the soda then also dissolves the vegetable mold and causes blackish spots in the soil, popularly known as black alkali.

(4) The injury caused by carbonate of soda is aggravated by its action in puddling the soil so as to cause it to lose its flaky condition, rendering it almost or quite untillable. It also tends to form in the depths of the soil layer a tough hardpan, impervious to water, which yields to neither plow, pick, nor crowbar, and renders drainage and leaching impossible. Its presence is easily ascertained by means of a pointed steel sounding rod.

(5) While alkali lands share with other soils of the arid region the advantage of unusually high percentages of plant-food in the insoluble form,* they also contain, alongside of the noxious salts, considerable amounts of water-soluble plant-food. When, therefore, the action of the noxious salts is done away with, they should be profusely and lastingly productive; particularly as they are always naturally somewhat moist in consequence of the attraction of moisture by the salts, and are therefore less liable to injury from drought than the same soils when free from alkali.

Utilization and Reclamation of Alkali Lands.

The most obvious mode of utilizing alkali lands is to occupy them with useful plants that are not affected by the noxious salts. Unfortunately, as has already been stated, but few such crops of general utility, especially for the commercial and labor conditions of this country, have as yet been found. Practically the most important problem is to render these lands available for our ordinary cultures, by methods financially possible.

Counteracting Evaporation.—Since evaporation of the soil moisture at the surface is what brings the alkali salts to the level where the main injury to plants occurs, it is obvious that evaporation should be prevented as much as possible. This is the more important, as the saving of soil moisture, and therefore of irrigation water, is attainable by the same means.

Three methods for this purpose are usually practiced by farmers and gardeners, viz, shading, mulching, and the maintenance of loose tilth in the surface soil to such depth as may be required by the climatic conditions.

*See Bulletin No. 3 of the U. S. Weather Bureau, 1892; Report California Station, 1894–5.

As to mulching, it is already well recognized in the alkali regions of California as an effective remedy in light cases. Fruit trees are frequently thus protected, particularly while young, after which their shade alone may (as in the case of low-trained orange trees) suffice to prevent injury. The same often happens in the case of low-trained vines, small fruit, and vegetables. Sanding of the surface to the depth of several inches was among the first attempts in this direction; but the necessity of cultivation, involving the renewal of the sand each season, renders this a costly method. Straw, leaves, and manure have been more successfully used; but even these, unless employed for the purpose of fertilization, involve more expense and trouble than the simple *maintenance of very loose tilth of the surface soil throughout the dry season;* a remedy which, of course, is equally applicable to field crops, and in the case of some of these—e. g., cotton—is a necessary condition of cultural success everywhere. The wide prevalence of "light" and deep soils in the arid regions, from causes inherent in the climate itself,* renders this condition of relatively easy fulfilment.

Diluting the Alkali Salts.—Aside, however, from the mere prevention of surface evaporation, another favorable condition is realized by this procedure, namely, the commingling of the heavily salt-charged surface layers with the relatively nonalkaline subsoil. Since in the arid regions the roots of all plants retire farther from the surface because of the deadly drought and heat of summer, it is possible to cultivate deeper than could safely be done with growing crops in humid climates. Yet even here, the maxim of "deep preparation and shallow cultivation" is put into practice with advantage, only changing the measurements of depth to correspond with the altered climatic conditions. Thus, while in the eastern United States four inches is the accepted standard of depth for summer cultivation to preserve moisture without injury to the roots, that depth must in the arid region frequently be doubled in order to be effective, and will even then scarcely touch a living root in orchards and vineyards in unirrigated land.

A glance at Fig. 1 (p. 7) will show the great advantage of extra deep preparation in commingling the alkali salts accumulated near the surface with the lower soil layers, diffusing the salts through 12 instead of 6 inches of soil mass. This will in very many cases suffice to render the growth of ordinary crops possible if, by subsequent frequent and thorough cultivation, surface evaporation, and with it the reascent of the salts to the surface, is prevented. A striking example of the efficiency of this mode of procedure was given at the Tulare substation, where a portion of a very bad alkali spot was trenched to the depth of two feet, throwing the surface soil to the bottom. The spot

* See reference on preceding page.

thus treated produced excellent wheat crops for a few years—the time it took the alkali salts to reascend to the surface.

It should therefore be kept in mind that whatever else is done toward reclamation, *deep preparation* and *thorough cultivation* must be regarded as prime factors for the maintenance of production on all alkali lands.

The efficacy of shading, already referred to, is strikingly illustrated in the case of some field crops which, when once established, will thrive on fairly strong alkali soil, provided that a good thick "stand" has once been obtained. This is notably true of the great forage crop of the arid region, alfalfa, or lucern. Its seed is extremely sensitive to black alkali, and will decay in the ground unless protected against it. But when once a full stand has been obtained, the field may endure for many years without a sign of injury. Here two effects combine, viz, the shading, and the evaporation through the deep roots and abundant foliage, which alone prevents, in a large measure, the ascent of the moisture to the surface. The case is then precisely parallel to that of the natural soil (see Fig. 2), except that, as irrigation is practiced in order to stimulate production, the sheet of alkali hardpan will be dissolved and its salts spread through the soil more evenly. The result is that oftentimes, so soon as the alfalfa is taken off the ground and the cultivation of other crops is attempted, an altogether unexpectedly large amount of alkali comes to the surface and greatly impedes, if it does not altogether prevent, the immediate planting of other crops. Shallow-rooted annual crops that give but little shade, like the cereals, while measurably impeding the rise of the salts during their growth, frequently allow of enough rise after harvest to prevent reseeding the following season.

Chemical Remedies.

Of the three sodium salts that usually constitute the bulk of "alkali" only the carbonate of soda is susceptible of being materially changed by any agent that can practically be applied to land. So far as we know, the salt of sodium least injurious to ordinary vegetation is the sulphate, commonly called glauber salt, which ordinarily forms the chief ingredient of white alkali. Thus barley is capable of resisting about five times more of the sulphate than of the carbonate, and quite twice as much as of common salt. Since the maximum percentage that can be resisted by plants varies materially with the kind of soil, it is difficult to give exact figures save with respect to particular cases. For the sandy loam of the Tulare substation the maximum for cereals may be approximately stated to be one tenth of one per cent (0.1) for salsoda, a fourth of one per cent (0.25) for common salt, and from forty-five to fifty one hundredths of one per cent (0.45–.50) for glauber salt, within the first foot from the surface. For clay soils the tolerance is markedly less, especially as regards the salsoda, since in their case the

injurious effect on the tilling qualities of the soil, already referred to, is superadded to the corrosive action of that salt; and in them, moreover, accumulation at the surface is more pronounced.

Since, then, so little carbonate of soda suffices to render soils uncultivable, it frequently happens that its mere transformation into the sulphate is sufficient to remove all stress from alkali. Gypsum (land-plaster) is the cheap and effective agent to bring about this transformation, *provided water be also present.* The amount required per acre will, of course, vary with the amount of carbonate of soda in the soil, all the way from a few hundred pounds to several tons in the case of strong alkali spots. But it is not usually necessary to add the entire quantity at once, provided that sufficient be used *to neutralize the alkali*

FIG. 5. Wheat growing in soil crusted with white alkali, originally a barren black alkali spot. Tulare Experiment Substation.

near the surface, and enough time be allowed for the action to take place. In very wet soils this may occur within a few days; in merely damp soils, in the course of months; but usually the effect increases for years, as the salts rise from below. For the complete neutralization of each 1,000 pounds of carbonate of soda in the land, 1,630 pounds of pure gypsum is required. But of the impure, 80–85% article as now on the market in California, an even double quantity, or 2,000 pounds, would be the proper dose.

The effect of gypsum on the black-alkali soil of Tulare substation was to change a barren spot into a tract which produced a fine crop of wheat, although the surface of the soil was covered with a crust of the white alkali (sulphate of soda). This is shown in the accompanying hotograph (Fig. 5).

The effect of gypsum on black alkali land is often very striking, even to the eye. The blackish puddles and spots disappear, because the gypsum renders the dissolved humus insoluble and thus restores it to the soil. The latter soon loses its hard, puddled condition and crumbles and bulges into a loose mass, into which water now soaks freely, bringing up the previously depressed spots to the general level of the land, and permitting free subdrainage. On the surface thus changed seeds now germinate and grow without hindrance; and as the injury from alkali occurs at or near the surface, it is usually best to simply harrow in the plaster, leaving the water to carry it down in solution. Soluble phosphates present are decomposed, so as to retain finely divided but less soluble phosphates in the soil.

Trees and vines already planted may be temporarily protected from the worst effects of the black alkali by surrounding the trunks with gypsum or with earth abundantly mixed with it. Seeds may be similarly protected in sowing, and young plants in planting.

It must not be forgotten that this beneficial change may go backward if the land thus treated is permitted to be swamped by excess of irrigation water, or otherwise. Under the same conditions, naturally white alkali may turn black; and no amount of gypsum used can prevent or undo this until the excess of water is drained off and the soil allowed time for aëration. Thus while excessive irrigation is injurious at all times in diminishing the depth of root-growth and the feeding area of the plant, it is especially so when alkali is present. Of course, gypsum is of no benefit whatever on soils containing no salsoda, but only glauber and common salt.

Stable Manure and Other Fertilizers.—Under the impression that alkali land is poor in plant-food, farmers frequently try applications of stable manure and other fertilizers. As a rule, these applications are not only useless but even harmful. From their very mode of formation, alkali soils are exceptionally rich in plant-food, so that the addition of more can do no good. In the case of stable manure being used on black alkali ground, a pungent odor of ammonia is given off whenever the sun shines, and plants otherwise doing well are thus injured or killed. When well plowed-in, stable manure will sometimes prevent to some extent the rise of alkali by diminishing evaporation; but its usefulness in that respect is readily replaced by good tillage. The main benefit obtained is the addition of humus to soils that have been whitened by alkali action.

Potash salts, especially kainit, are wholly useless and add to the alkali trouble; potash is always abundantly present in alkali lands, even in the water-soluble condition. Nitrates, also, are always present in alkali soils in sufficient amounts for plant growth, sometimes to

excess. Phosphates may sometimes be useful, but will rarely be needed for some years. Greenmanuring, on the other hand, is a very desirable improvement on all alkali lands.

Removing the Salts from the Soil.

In case the amount of salts in the soil should be so great that even the change worked by gypsum is insufficient to render it available for useful crops, the only remedy left is to remove the salts partially or wholly from the land. Two chief methods are available for this purpose. One is to remove the salts, with more or less earth, from the surface at the end of the dry season, either by sweeping, or by means of a horse scraper set so as to carry off a certain depth of soil. Thus sometimes in a single season one third or one half of the total salts may be got rid of, the loss of a few inches of surface soil being of little moment in the deep soils of the arid region. The other method is to leach them out of the soil into the country drainage, supplementing by irrigation water what is left undone by the deficient rainfall.

It is not practicable, as many suppose, to wash the salts off the surface by a rush of water, as they instantly soak into the ground at the first touch. Nor is there any sensible relief from allowing the water to stand on the land and then drawing it off; in this case also the salts soak down ahead of the water, and the water standing on the surface remains almost unchanged. In very pervious soils, and in the case of white alkali, the washing-out can often be accomplished without special provision for underdrainage, by leaving the water on the land sufficiently long. But the laying of regular underdrains greatly accelerates the work, and renders success certain.

An important exception, however, occurs in the case of black alkali in most lands. In this case either the impervious hardpan or (in the case of actual alkali spots) the impenetrability of the surface soil itself, will render even underdrains ineffective unless the salsoda and its effects on the soil are first destroyed by the use of gypsum, as above detailed. This is not only necessary in order to render drainage and leaching possible, but is also advisable in order to prevent the leaching-out of the valuable humus and soluble phosphates, which are rendered insoluble (but not unavailable to plants) by the action of the gypsum. Wherever black alkali is found, therefore, the application of gypsum should precede any and all other efforts toward reclamation.

Another method for diminishing the amount of alkali in the soil is the cropping with plants that take up considerable amounts of salts. In taking them into cultivation, it is advisable to remove entirely from the land the salt growth that may naturally cover it, notably the greasewoods (*Allenrolfea*, *Sarcobatus*), with their heavy percentages of alkaline ash. Crop plants adapted to the same object are mentioned farther on.

Will It Pay to Reclaim Alkali Lands?

This is a question naturally asked when considering the nature and expense of the operation involved, especially when the last resort—underdraining and leaching—has to be adopted.

Those familiar with the alkali regions are aware how often the occurrence of alkali spots interrupts the continuity of fields and orchards, of which they form only a small part, but enough to mar their aspect and cultivation. Their increase and expansion under irrigation frequently render their reclamation the only alternative of absolute abandonment of the investments and improvements made, and from that point of view alone it is of no slight practical importance. Moreover, the occurrence of vast continuous stretches of alkali lands within the otherwise most eligibly situated portions of the irrigation region forms a strong incentive toward their utilization.

There is, however, a strong intrinsic reason pointing in the same direction, namely, the almost invariably high and lasting productiveness of these lands when once rendered available to agriculture. This is foreshadowed by the usually very heavy and luxuriant growth of native plants around the margins of and between alkali spots (see Fig. 6); that is, wherever the amount of injurious salts present is so small as not to interfere with the utilization of the abundant store of plant-food which, under the peculiar conditions of soil formation in arid climates, remains in the land instead of being washed into the ocean. Extended comparative investigations of soil composition, as well as the experience of thousands of years in the oldest settled countries of the world, demonstrate this fact and show that so far from being in need of fertilization, alkali lands possess extraordinary productive capacity whenever freed from the injurious influence of the excess of useless salts left in the soil in consequence of deficient rainfall. Alkali salts are actually scraped up and carried to the cultivated fields in sacks in parts of Turkestan, the peasants considering that "the salt is the life of the land." (Middendorf).

It does not, of course, follow that alkali lands are good lands for farmers of limited means to settle upon. On the contrary, like most other business enterprises, they require a certain amount of capital and lapse of time to render them productive. They are not therefore a proper investment for farmers or settlers of small means, dependent on annual crops for their livelihood and unable to bring to bear upon these soils the proper means for their reclamation; unless, indeed, local conditions should enable them to use successfully some of the crops specially adapted to alkali lands.

Fig. 6. Alkali Lands in San Joaquin Valley, California.

Crops Suitable for Alkali Lands.

As has already been stated, the search for generally available crops that will thrive in strong, unreclaimed alkali land has not thus far been very successful. It is true that cattle will nibble alkali grass (*Distichlis spicata*), but will soon leave it for any dry feed that may be within reach. The same is true of all the fleshy plants that grow on the stronger alkali lands, and are known under the general designation of alkali weeds. When stock unaccustomed to it are forced by hunger to feed on such vegetation to any considerable extent, disordered digestion is apt to result; which in such ranges, however, is often counteracted by feeding on aromatic or astringent antidotes, such as the gray sagebrush and the more or less resinous herbage of plants of the sunflower family. In the Great Basin region, lying between the Sierra Nevada and the front range of the Rocky Mountains, there are, aside from the grasses, numerous herbaceous and shrubby plants that afford valuable pasturage for stock,* and some of these grow on moderately strong alkali land; the same is true in California. It is quite possible that some of these will be found to lend themselves to ready propagation for culture purposes as well as they do for restocking the ranges. But thus far none have found wider acceptance, probably because their stiff branches and upright habit render them inconvenient to handle. It will require more extended experience and experiment before any of these can be definitely adopted by farmers.

Experience in California indicates that in the more southerly portion of the arid region the unpalatable native plants may be generally replaced, even on the ranges, by one or more species of the Australian saltbushes (*Atriplex* spp.), long ago recommended by Baron von Mueller of Melbourne; of which one (*A. semibaccata*) has proved eminently adapted to the climate and soil of California and is readily eaten by all kinds of stock. The facility with which it is propagated, its quick development, the large amount of feed yielded on a given area, even in the strongest alkali land ordinarily found, and its thin, flexible stems, permitting it to be handled very much like alfalfa, seem to commend it specially to the farmer's consideration wherever the climate will permit of its use. Its resistance to severe cold weather has not yet been adequately tested. It is probable that other species, now also under trial, will equally justify the recommendation given them by the eminent botanist who first brought them into public notice as promising forage plants. Most of the species have an upright, shrubby habit, which adapts them rather to browsing than to use as a

* See Bulletin No. 16 of the Wyoming Experiment Station; also Bulletins Nos. 2 and 12 of the Division of Agrostology, and Farmers' Bulletin No. 108, U. S. Department of Agriculture.

forage crop. Among the best next to the *semibaccata* are the species *leptocarpa* and *halimoides*, the former somewhat similar in habit to the *semibaccata* but not so rapid a grower. A special bulletin on the saltbushes, Australian as well as native, has been published by this Station and will be sent on request.

It is to be noted that since the saltbushes take up nearly one fifth of their dry weight of ash ingredients*, largely common salt, the complete removal from the land of a five-ton crop of saltbush hay will take away nearly a ton of the alkali salts per acre. This will in the course of some years be quite sufficient to reduce materially the saline contents of the land, and will frequently render possible the culture of ordinary crops.

Next to the saltbushes the Chilean plant *Modiola decumbens* (now commonly known as modiola simply), of the mallow family, deserves attention. Accidentally introduced as a weed with other seeds, by the Kern County Land Company at Bakersfield, it attracted attention by its persistence on alkali lands, and by the observation that cattle ate it freely. It was then grown on a larger scale, and found to make acceptable pasture where alfalfa could not be grown on account of alkali. It is a trailing plant with medium-sized, roundish foliage, and roots freely at the joints where they touch the ground. Unlike the saltbushes it is therefore a formidable weed where it is not wanted; but as according to our determinations it resists as much as 52,000 pounds of salts per acre, even when 41,000 of these is common salt, it is likely to be useful in many cases, particularly as an admixture to a saltbush diet for stock, the more as it does not absorb as much salt as the latter. Owing to the rooting habit of the stems, it is not as convenient to handle as the *semibaccata* saltbush, nor, probably, will it yield as much fodder in a season. It seems best adapted to pasturage.

Another forage plant which it may hereafter pay to propagate artificially on strong alkali land, is the tussock-grass (*Sporobolus airoides*), of which a figure is given on page 37. Indicating as it usually does when growing naturally, land too strongly impregnated to be reclaimable at this time, but being freely eaten by stock, it seems worth while to count it among the possible pasture grasses for land too strongly alkaline to bear ordinary crops. Its seed can be abundantly gathered in its native habitats, indicated below.

---

*Analyses made at the California station show 19.37 per cent of ash in the air-dry matter of Australian saltbush. (See California Sta. Bul. 105; E. S. R., vol. 6, p. 718.) Analyses of Russian thistle have been reported showing over 20 per cent of ash in dry matter. (See Minnesota Sta. Bul. 34; Iowa Sta. Bul. 26; E. S. R., vol. 6, pp. 552, 553.)

Amount of Salts Compatible with Ordinary Crops.

Since the amount of alkali that reaches the surface layer is largely dependent upon the varying conditions of rainfall or irrigation and surface evaporation, it is difficult to foresee to what extent that accumulation may go, unless we know the total amount of salts present that may be called into action. This can be ascertained by a summation of the results obtained and shown in the above diagrams for each layer, but more readily by the examination of one sample representing the average of the entire soil column of 4 feet. By calculating the figures so obtained to an acre of ground, we can at least approximate the limits within or beyond which crops will succeed or perish.

Grasses.—Applying this procedure to the cases investigated at the Tulare substation, and estimating the weight of the soil per acre-foot at 4,000,000 pounds, we find for the land on which *barley* refused to grow the figure 32,480 pounds of total salts per acre, corresponding to 0.203 per cent; while for the land on which barley gave a full crop we find 25,440 pounds, equivalent to 0.159 per cent for the whole soil column of 4 feet. It thus appears that for barley the limits of tolerance lie between the above two figures, which might, of course, have been obtained equally well from an average sample of the 4-foot column by making a single analysis. It should be noted that in this case a full crop of barley was grown even when the alkali consisted of fully one half of the noxious carbonate of soda, proving that it is not necessary in every case to neutralize the *entire* amount of that salt by means of gypsum, which in the present case would have required about 9½ tons of gypsum per acre—a prohibitory expenditure.

Rye appears to be about like barley in its tolerance of alkali salts; while wheat is somewhat more sensitive. In fact, the superficial rooting and fine fibrous roots of the true grasses render them, as a whole, rather sensitive to alkali salts; yet there are a number of the perennial kinds whose thick roots and deeper rooting render them measurably resistant. Aside from the alkali grass proper (*Distichlis*), the so-called rye grass of the Northwest (*Elymus condensatus*) is probably, next to the tussock-grass, the most resistant species among the wild grasses. Its southern form, with several others not positively identified, occupy largely the milder alkali lands of Southern California, such as the low lands near Chino producing choice sugar beets on a close-textured silty loam.

While maize is rather sensitive, and fails on even slightly alkaline lands, Egyptian corn and other sorghums, rooting somewhat deeper, and having stout roots, do well on mild alkali soils of the white class. The same appears to be true of some of the stout-rooted millets, such as barnyard grass (*Panicum crus-galli*), of which the variety (?) *muti-*

cum is reported to succeed well in neutral alkali land. One of the most successful grasses on the light alkali lands near Chino, where most of the commonly cultivated kinds fail, was a near relative of the barnyard grass, the *Eleusine coracana*, which produces heavy crops of a millet-like grain much relished by poultry and also by stock. This grass (of which seed can be obtained from the Station) has succeeded all over the ground whose alkali content ranges up to 12,000 pounds per acre. Next to this, in point of success, were the pearl millet (*Pennisetum typhoideum*) and teosinte, Hungarian brome grass, and Japanese millet, on land containing about 9,000 pounds of salts per acre. The loliums, including the darnel ("California cheat"), and the Australian and Italian ray ("rye") grasses, succeed fairly on land containing as much as 6,000 pounds of (white) salts. Most other cultivated grasses failed conspicuously alongside of these. It must be remembered that in more loose-textured, sandy lands than those in which these tests were made, the above figures for tolerance would probably be increased by 30 per cent or more.

Doubtless some of the indigenous grasses of the interior plateau region and the great plains east of the Rocky Mountains, such as the buffalo and grama grasses, as well as several of the wheat grasses (*Agropyron*) and bunch grasses (*Festuca*, *Poa*, *Stipa*, etc.) will prove resistant to larger proportions of alkali than the meadow and pasture grasses of the regions of summer rains.

Legumes.—Both the natural growth of alkali lands and experimental tests seem to show that this entire family (peas, beans, clovers, etc.) are among the more sensitive and least available wherever black alkali exists, while fairly tolerant of the white (neutral) salts. Apparently a very little salsoda suffices to destroy the tubercle-forming organisms that are so important a medium of nitrogen-nutrition in these plants. Alfalfa, with its hard, stout, and long taproot, seems to resist best of all these plants, excepting the melilots. As a general thing, taprooted plants, when once established, resist best, for the obvious reason that the main mass of their feeding roots reaches below the danger level. Another favoring condition, already alluded to, is heavy foliage and consequent shading of the ground; alfalfa happens to combine both of these advantages. There has been some difficulty in obtaining a full stand of alfalfa in the portion of the Chino tract containing from 4,000 to 6,000 pounds of alkali salts per acre; but once obtained it has done very well. The only other plant of this family that succeeds well on this land, and even (at Tulare) on soil considerably stronger (probably between 20,000 and 30,000 pounds) are the two melilots, *M. indica* and *alba;* the latter (the Bokhara clover) is a forage plant of no mean value in moist climates, but somewhat restricted in its use in California because of the very high aroma it develops, especially in alkali lands; so that stock will eat only

limited amounts, best when intermixed with other forage, such as the saltbushes. The yellow melilot is highly recommended by the Arizona station as a greenmanure plant for winter growth; but in this State it is a summer-growing plant only, and is refused by stock. Very few plants belonging to this family are naturally found on alkali lands, and attempts to grow them, even where only glauber salt is present, have been but very moderately successful. The salts seem to retard or even prevent the formation of the tubercles useful for nitrogen absorption; and for most of the legumes the limit of full success seems to lie between 3,000 and 4,000 pounds to the acre.

Weeds.—Like the legumes, wild plants of the *mustard* family are rare on alkali lands; and correspondingly, the cultivated mustard, kale, rape, etc., fail even on land quite weak in alkali. Their limit of tolerance seems to lie near 4,000 to 5,000 pounds per acre of even white salts.

Several of the hardiest of the native "alkali weeds" belong to the *sunflower* family, and the common wild sunflowers (*Helianthus californicus* and *H. annuus*) are common on lands pretty strongly alkaline. Correspondingly, the "Jerusalem artichoke," itself a sunflower, is among the available crops on moderately strong alkali soils; and so, doubtless, are other members of the same relationship not yet tested, such as the true artichoke, salsify, etc. Chicory, belonging to the same family, yielded roots at the rate of 12 tons per acre, on land on the Chino tract containing about 8,000 pounds of salts per acre.

Root Crops.—It seems to be generally true that root crops suffer in quality, however satisfactory may be the quantity harvested on lands rich in salts, and especially in chlorids (common salt). It was noted at the Tulare substation that the tubers of the artichoke were inclined to be "squashy" in the stronger alkali land, and failed to keep well; the same was true of potatoes, which were very watery; and also of turnips and carrots. It is a fact well known in Europe, that potatoes manured with kainit (chlorids of potassium and sodium) are unfit for the manufacture of starch, and are generally of inferior quality. But this is found not to be the case when, instead of the chlorids, the sulphate is used; hence the advice, often repeated by this Station, that farmers desiring to use potash fertilizers should call for the "high-grade sulphate" instead of the cheaper kainit, which adds to the injurious salts already so commonly present in California lowland soils.

The common *beet* (including the mangel-wurzel) is known to succeed well on saline seashore lands, and it maintains its reputation on alkali lands also. Being specially tolerant of common salt, it may be grown where other crops fail on this account; but the roots so grown are strongly charged with common salt, and have, as is well known, been

used for the purpose of removing excess of the same from marsh lands. Such roots are wholly unfit for sugar-making.

It is quite otherwise with glauber salt (sodium sulphate); and as this is usually predominant in alkali lands, either before or after the gypsum treatment, this fact is of great importance, for it permits of the successful growing of the sugar beet; as has been abundantly proved at the Chino ranch, where land containing as much as 12,000 pounds of salts, mostly this compound, has yielded roots of very high grade both as to sugar percentage and purity.

Asparagus is another crop which bears considerable amounts of common salt as well as of glauber salt; but not of salsoda, which must first be transformed by the use of gypsum.

Rhubarb was a conspicuous failure in even the weak alkali lands of the Chino tract.

Textile Plants.—Japanese hemp seemed to have a hard struggle with the alkali while young, but at the end of the season stood 8 feet high. The ramie plant, also, will bear moderately strong alkali, apparently somewhat over 12,000 pounds per acre. Flax has not been tested in cultivation; but its wide distribution all over the States of Oregon and Washington would seem to indicate that it is not very sensitive. Another textile plant, the Indian mallow (*Abutilon avicennæ*), was found to fail on the Chino alkali soil.

Grapevines.—The *Vitis vinifera* is quite tolerant of white or neutral alkali salts, and will resist even a moderate amount of the black so long as no hardpan is allowed to form. At the Tulare substation, it was found that grapevines did well in sandy land containing 35,230 pounds of alkali salts, of which one half was glauber salt, 9,640 pounds carbonate of soda, 7,550 pounds common salt, and 750 pounds nitrate of soda. They were badly distressed where, of a total of 37,020 pounds of alkali salts, 25,620 pounds was carbonate of soda; while where the vines had died out, there was found a total of 73,930 pounds, with 37,280 pounds of carbonate. The European vine, then, is considerably more resistant of alkali, even in its worst (black) form, than barley and rye; and it seems likely that the native grapevines of the Pacific Coast, *Californica* and *Arizonica*, would resist even better; a point still under experiment.

Experience, however, has shown that vines rapidly succumb when by excessive irrigation the bottom water is allowed to rise, increasing the amount of alkali salts near the surface and shallowing the soil at their disposal. Such over-irrigation has been a fruitful cause of injury to vineyards in the Fresno region, and would doubtless if practiced kill most of the vines at Tulare substation which are now flourishing. In such cases sometimes the formation of hardpan is followed by that of a

concentrated alkaline solution above it, strong enough to corrode the roots themselves, and not only killing the vines, but rendering the land unfit for any agricultural use whatsoever. The swamping of alkali lands, whether of the white or black kind, is not only fatal to their present productiveness, but, on account of the strong chemical action thus induced, greatly jeopardizes their future usefulness. Many costly investments in orchards and vineyards have thus been rendered unproductive, or have even become a total loss.

Citrus Trees.—These are *on the whole* rather sensitive to alkali, especially while young; so that it is often difficult to obtain a stand even when, later on, the feeding roots descend beyond the reach of injury. In the close-textured lands of Chino, young trees hardly maintained life with more than 5,000 pounds of total salts. Common salt seems to be particularly injurious; near Riverside, full-grown trees perished under the influence of bottom water containing 0.25 per cent or 146 grains of salt per gallon, which impregnated the ground; corresponding to about 9,000 pounds per acre in four feet.

In the sandy loam lands near Corona, trees eight years old suffered severely when by irrigation with alkali water the alkali content of the land reached 11,000 pounds per acre; as illustrated in Plates 7 and 8, pages 32 and 33. At another point in the same region, two representative trees were selected for comparison, five rows apart on land absolutely identical; one of these retained its leaves, though suffering, the other was completely leafless. The leaching of the alkali to the depth of 4 feet gave the following results, calculated to pounds per acre:

	Sulphates.	Carbonates.	Chlorids.	Total.
Poor tree	4,720	1,680	2,520	8,920
Better tree	4,120	2,360	720	7,200

Here it is apparently the excess of common salt to which the difference is due, and this despite the higher content of carbonate of soda in the soil bearing the better tree.

On the other hand, at the Tulare substation, orange trees (sour stock) maintain vigorous growth and good bearing in a very sandy tract which to the depth of 7 feet showed an aggregate content of 26,840 pounds of salts (or 22,780 to 4 feet depth); but which is never irrigated. (See diagram, page 10.) The salts in this case consist wholly of *sulphate* and *carbonate of soda* in the ratio of 54 to 42, implying the presence of nearly 12,000 pounds of salsoda within reach of the tree roots; yet in the absence of common salt, no perceptible injury or even stress upon the trees has been noted.

In view of these facts, it seems that common salt is the portion of alkali by far most injurious to citrus trees, and that great care should be taken in the use of irrigation waters to exclude those charged with

common salt; also, to avoid locating citrus orchards where common salt pre-exists in the land.

Deciduous Orchard Trees.—Of these, strangely enough, the almond seems to resist best. The peach is more sensitive; the apricot does fairly. Plum trees as such are nearly as resistant as peaches, but sometimes suddenly begin to fail when beginning to bear; the fruit appears normal on the outside for a time, but the pit fails to form, being sometimes flattened out like a piece of pasteboard; and the fruit fails to mature. Apples are rather sensitive; pears considerably less so, doing well even when the outside bark around the root crown is blackened by the alkali. The olive is quite resistant; the fig less so. The English walnut resents even a slight taint of black alkali, but is fairly tolerant of "white" salts, as is shown in the peculiarly suitable light loam soils on the lower Santa Clara River, in Ventura County.

Figures for the limits of alkali tolerance in the case of the deciduous orchard trees have not yet been closely determined, owing to the difficulties inherent in the differences of root penetration in the several soils and localities. On the ten-acre tract near Chino, therefore on a rather close-textured soil, apple trees have done very well on land containing one fourth of one per cent of ("white") salts, or between 10,000 and 11,000 pounds per acre. On similar soil, the quince appears to be perfectly at home.

Timber and Shade Trees.—Of trees suitable for alkali lands, two native ones call for mention. One is the California white or valley oak (*Quercus lobata*), which forms a dense forest of large trees on the delta lands of the Kaweah River in California, and is found scatteringly all over the San Joaquin Valley (see frontispiece). Unfortunately, this tree does not supply timber valuable for aught but firewood or fence posts, being quite brittle. The native *cottonwoods*, while somewhat retarded and dwarfed in their growth in strong alkali, are quite tolerant of the white salts, especially of glauber salt.

Of other trees, the oriental plane, or sycamore, and the black locust, have proved the most resistant in the alkali lands of the San Joaquin Valley; and the former being a very desirable shade tree, it should be widely used throughout the regions where alkali prevails more or less. The ailantus is about equally resistant, and but for the evil odor of its flowers, deserves strong commendation. Of the eucalypts, the narrow-leaved *Eucalyptus amygdalina* (one of the "red gums") seems to be least sensitive, and in some cases has grown as rapidly as anywhere. The *E. rostrata*, as well as the pink-flowered variety of *E. sideroxylon*, are now doing about as well as the *amygdalina* at Tulare, where at first they seemed to suffer. The common blue gum, *E. globulus*, is much more sensitive.

Of the acacias, the tall-growing *A. melanoxylon* ("black acacia") resists pretty strong alkali, even on stiff soil; as can be seen at Tulare and Bakersfield, where there are trees nearly two feet in diameter. The beautiful *A. lophantha* (*Albizzia*) has in plantings made along the San Joaquin Valley Railroad shown considerable resistance, likewise; but it is quite sensitive to frost.

One of the "Australian pines, *Casuarina equisetifolia*," was transplanted experimentally on station grounds of the Valley Railroad from the Chico forestry substation, and a number are growing very well in alkali lands. This tree is credited by Maiden with being tolerant of "saline soil." Doubtless many others of the *Casuarina* tribe will be found similarly resistant.

Of *Eastern trees*, the elms have done fairly well, but the tulip tree, the linden, the English oak, and most other trees of the Atlantic States, become stunted. Among those doing fairly well is the honey locust; but its thorns and imperfect shade render it not very desirable.

The California maple (*Acer macrophyllum*) and box elder (*Negundo californica*) have done fairly well in the lighter alkali lands at Tulare.

A most remarkably alkali-resistant shrub or small tree is the pretty *Koelreuteria paniculata*, which at Tulare is growing in some of the strongest alkali soil of the tract. Unfortunately it is available mainly for ornamental purposes; its wood, while small, is very hard and makes excellent fuel.

Irrigation with Saline Waters.

It would hardly seem necessary to emphasize specially the danger incurred in irrigation with waters containing unusual amounts of soluble salts; since ordinary common sense clearly indicates the impropriety of increasing the saline contents of soils already charged with them, by the evaporation, year after year, of large masses of saline water. Yet experience has shown that the eagerness to utilize for irrigation whatever water happens to be convenient to good lands, often overcomes both that sense, and the warning given by the published analyses of such waters. Without specifiying localities, it may be said that great injury has already been done in California by the disregard of obviously needful caution in this respect. The very slight taste possessed by glauber salt and salsoda does not adequately indicate their presence even when in injurious amounts; so that frequently a chemical test of the waters is the only definite guide. A few general rules, however, will help to enable the irrigator to determine whether or not such examination is called for.

It may be taken for granted that *the waters of all lakes having no regular outflow are unfit for regular irrigation use;* since they must needs contain all the accumulations of salts from the secular evaporation of the waters that flow into them.

The plates annexed exhibit the cultural results of several years' irrigation with the waters of Lake Elsinore, Riverside County, as compared with the growth of orange trees on the same land, but irrigated with artesian water. Lake Elsinore is fed by the San Jacinto River, and in wet years sometimes overflows for a few weeks into Temescal Creek. Thus its saline content varies somewhat, from about 80 to over 100 grains per gallon, of salts containing three-fifths of common salt and one-fifth each of glauber salt and carbonate of soda. The latter, as already stated, tends to form a hardpan in the subsoil, and such hardpan was actually formed where the water was used; and afterward prevented its proper penetration, so that the trees suffered from dryness of their lower roots, while damaged by the alkali salts near the surface. As mentioned before, experience elsewhere has shown that citrus trees are especially sensitive to common salt.

The investigations made by the Station have, moreover, shown that aside from the frequently saline character of the well and even the artesian waters of the petroleum-bearing region of the State in the coast ranges, the streams of that region, especially the smaller ones, are sometimes too strongly charged with "alkali" (in this case largely the sulphates of soda and magnesia) to be suitable either for irrigation or domestic use. Toward the end of the dry season, even the larger streams of the southern coast ranges, with their diminished flow, sometimes show an excess of salts. This seems also to be true of the San Jacinto River, which feeds Elsinore Lake.

The waters flowing from the Sierra Madre, south of the Tehachapi range, are throughout of excellent quality for irrigation purposes; as are all those flowing from the Sierra Nevada. The same is true of the artesian waters of the valley of Southern California, from Los Angeles east to Redlands, and of all the deeper borings of the Antelope Valley.

In the Great Valley, the artesian waters vary greatly in quality. Those of Kern and Tulare counties are mostly good, sometimes exceptionally so, as in the case of the water-supply of Tulare City. It is only the shallower borings, near the borders of Tulare Lake, that some waters strongly charged with carbonate of soda or other salts have been found. From Fresno and Merced we have few data as yet; but it seems that north of a line drawn from northeastern Stanislaus via Tracy to Point of Timber, saline waters, sometimes accompanied by some gas, occur at certain levels. But the deep wells bored at Stockton and Sacramento, and northward, have good potable water.

Limits of Saline Contents.—Unfortunately it is not easy to give absolute rules in regard to the exact figures that constitute an excess of salts for irrigation purposes, since not only the composition of the salts, but also the nature of the land to be irrigated, and the frequency of irrigation required, must be taken into consideration.

FIG. 7. ORANGE TREES IRRIGATED WITH ARTESIAN WATER.
Alkali in 4 feet of soil = 2,560 pounds per acre, chiefly sulphate of soda.

FIG. 8. ORANGE TREES IRRIGATED 3 YEARS WITH ALKALI LAKE WATER.
Alkali in 4 feet of soil = 8,920 pounds per acre: Sulphates 4,720, Carbonates 1,680, Chlorids 2,520.

Broadly speaking, the extreme limits of mineral content usually assigned for potable waters, viz, 40 grains per gallon, also applies to irrigation waters. Yet it sometimes happens that all or most of the solid content is gypsum and epsom salt; when only a large excess of the latter would constitute a bar to irrigation use. When, on the contrary, a large proportion of the solids consists of carbonate of soda or of common salt, even a smaller proportion of salts than 40 grains might preclude its *regular* use, depending upon the nature of the soil to be irrigated. For in a clay loam, or a heavy adobe, not only do the salts accumulate nearer to the surface, but the subdrainage being slow and imperfect (unless underdrained), it becomes difficult or impossible to wash out the saline accumulations from time to time, as is feasible in sandy lands. In these, moreover, as already stated, the alkali never becomes as concentrated near the surface as in heavier soils. Again, where *hardpan* exists in sandy land, saline irrigation-water soon saturates the soil mass above it with salts.

During the two dry seasons just past saline waters have frequently been used, exceptionally, in order to save trees threatened with death from drought. The Station has even advised that this should be done, with the proviso that *the salts so introduced must be washed into the subdrainage by heavy irrigation*, whenever practicable, even if the same saline water should have to be used for the purpose. For few such waters are sufficiently strong to injure vegetation *until concentrated by evaporation;* as can be seen from the vegetation growing close to the margins of alkaline lakes, with its roots immersed in the water.

The irrigator can determine for himself whether or not his water is of doubtful character, by evaporating a tablespoonful, or more, in a clean silver spoon (avoiding boiling). If the dry residue should form simply a thin, powdery-looking film on the polished metal, he may be assured that the water is all right. If, on the other hand, an obvious saline crust should remain, which will redissolve in water, he should either have an analysis made, or use the water in such a manner as to remove the accumulated salts from time to time by washing them into the subdrainage, if the nature of the soil permits. *A very abundant use of such waters is then preferable to a sparing one;* but the user should *assure himself that it really penetrates*, for otherwise, especially in case much carbonate of soda is present, a dense hardpan may be formed that will allow the trees to perish from drought despite all the water running in the irrigation furrows. A pointed steel probe, three-sixteenths of an inch square, provided with a cross-handle, like a hand auger, ought to be among the tools of every farmer for such tests of his subsoil. No farmer in the arid region can afford to be ignorant of the nature of the substrata within which the bulk of the roots of his crops must vegetate.

Reclaimable and Irreclaimable Alkali Lands as Distinguished by Their Natural Vegetation.

While, as shown above, the adaptation or non-adaptation of particular alkali lands to certain cultures may be determined by sampling the soil and subjecting the leachings to chemical analysis, it is obviously desirable that some other means, if possible available to the farmer himself, should be found to determine the reclaimability and adaptation of such lands for general or special cultures.

The natural plant growth seems to afford such means, both as regards the quality and quantity of the saline ingredients. The most superficial observation shows that certain plants indicate extremely strong alkali lands where they occupy the ground alone; others indicate preëminently the presence of common salt; the presence or absence of still others form definite or probable indications of reclaimability or non-reclaimability. Many such characteristic plants are well known to and readily recognized by the farmers of the alkali districts. "Alkali weeds" are commonly talked about almost everywhere; but the meaning of this term—*i. e.*, the kind of plant designated thereby—varies materially from place to place, according to climate as well as to the quality of the soil. Yet if these characteristic plants could be definitely observed, described, and named, while also ascertaining the amount and kind of alkali they indicate as existing in the land, lists could be formed for the several districts, which would indicate, in a manner intelligible to the farmer himself, the kind and degree of impregnation with which he would have to deal in the reclamation work, thus enabling him to go to work on the basis of his own judgment, without previous reference to this Station.

The carrying-out of such a plan involves, obviously, a very large amount of botanical as well as chemical work, which cannot be accomplished within a few seasons; and, in view of the wide differences in the vegetation of the several alkali regions of the State, the same work will have to be repeated to a certain extent in each of these regions. The object to be achieved is, however, of such high practical importance—an importance not remotely appreciated as yet by those not familiar with the enormous extent of otherwise desirable lands in this State that are more or less tainted with alkali—as to deserve the expenditure upon it of a large amount of work as promptly as possible.

The extreme limitation of funds under which the Agricultural College, together with the University as a whole, has been suffering for some years past, has thus far restricted the scope of these researches very closely, both geographically and otherwise. It is hoped that in the future, a close comparison of the native vegetation with the chemical determination of the quantity and kind of alkali corresponding to

certain plants, or groups of plants, naturally occurring on the land, may enable us to come to a sufficiently close estimate of the nature and capabilities of the latter from the native vegetation alone, or with the aid of test plants purposely grown. But before entering upon this complex problem, it has been thought best to determine, first of all, what lands may for present economic conditions be considered *irreclaimable*, because their improvement would involve an expense out of proportion with present land values. So far as large areas are concerned, this may probably be considered to be the case when tile underdrainage is required in order to wash out the salts; while of course smaller tracts, which interrupt the cultivation of fields, may frequently justify the laying of a few drain lines required to render them cultivable with the rest of the land.

As stated in the report of this Station for 1895–7, the field work of this investigation, both botanical and in the collection of the corresponding soil samples, has been done by Mr. Joseph Burtt Davy, Assistant Botanist to the Station, who also supplies the notes accompanying the same; while the laboratory work for the determination of the amounts and kinds of salts present in the several cases has been carried out by Prof. R. H. Loughridge.

The plants hereinafter mentioned, and figured for the benefit of the great majority of readers who would fail to recognize them from the botanical description alone, are then to be understood as indicating, *whenever they occupy the ground as an abundant and luxuriant growth*, that such land is irreclaimable for ordinary crops, unless underdrained for the purpose of washing out surplus salts. The occurrence merely of scattered, more or less stunted individuals of these plants, while a sure indication of the *presence* of alkali salts, does not necessarily show that the land is irreclaimable.

The plants which may best serve as such indicators in California are the following:

Tussock-grass (*Sporobolus airoides*, Torr.), Fig. 9;

Greasewood (*Sarcobatus vermiculatus* (Hook.) Torr.), Fig. 10;

Dwarf Samphire (*Salicornia subterminalis*, Parish, and other species), Fig. 11;

Bushy Samphire (*Allenrolfea occidentalis* (Wats.) Ktze.), Fig. 12;

Saltwort (*Suaeda Torreyana*, Wats., and *S. suffrutescens*, Wats.), Fig. 13;

Alkali-heath (*Frankenia grandifolia campestris*, Gray), Fig. 14;

Cressa (*Cressa cretica truxillensis*, Choisy), Fig. 15.

TUSSOCK-GRASS* (*Sporobolus airoides*, Torr.); Fig. 9.

The three sets of samples of Tussock-grass soil which have been analyzed show that the total amount of all salts present is in no case less than 49,000 pounds per acre, to a depth of four feet, and that it sometimes reaches the extraordinarily high figure of 499,000 pounds. Of these amounts the neutral salts (glauber salt and common salt) are usually in the heaviest proportion (glauber salt, 19,600 to 323,000 pounds per acre; common salt, 3,500 to 172,800); the corrosive salsoda varying from 3,000 to 44,000 pounds.—Tussock-grass apparently cannot persist in ground which is periodically flooded. It is of special importance because it is an acceptable forage for stock.

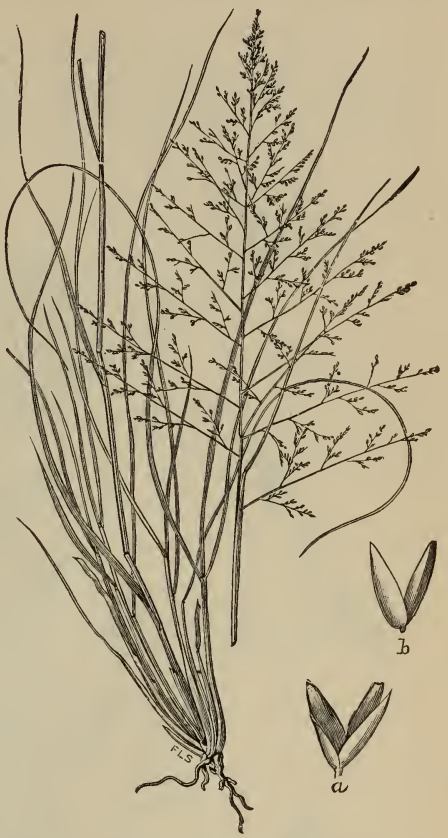

FIG. 9. TUSSOCK-GRASS—*Sporobolus airoides*, Torr. (From Division of Agrostology, U. S. Dept. Agr.)

Tussock-grass is a prevalent alkali-indicator in the hot, arid portions of the interior, from the upper San Joaquin Valley, the Mojave Desert, and southward; also through southern Nevada and Utah as far east as Kansas and Nebraska. In the San Joaquin Valley we have not found it farther north than the Tulare plains, although east of the Sierra it occurs near Reno. Coville observes that in the Death Valley region "it is confined principally to altitudes below 1,000 meters" (3,280 feet). Hillman, however, reports it from near Reno, Nevada, at an altitude which cannot be much less than 4,500 feet.

As we have received requests for precise information as to the localities in which this grass grows, from persons desiring to obtain seed for trial, the following list is given: Tulare plains, a few miles southeast of Tulare; a few miles south of Bakersfield; in the Antelope Valley; along the road from Rosamond to Lancaster, and in alkali sinks about the Leonis Valley between Lancaster and Elizabeth Lake. It is reported by Coville from Death Valley, Pahrump Valley, Resting-Springs Valley,

*So-called because it grows in large clumps or tussocks, which feature unfortunately is not indicated in the illustration.

Owens River Valley, and other points in the desert region southeast of the Sierra Nevada. It is also recorded from near Barstow and other points in San Bernardino County; in dry soils near Los Angeles, and from San Diego County.

GREASEWOOD* (*Sarcobatus vermiculatus* (Hook) Torr.); Fig. 10.

Through the courteous coöperation of Prof. F. H. Hillman, Botanist to the Nevada Agricultural Experiment Station at Reno, we have obtained three series of samples of Greasewood soil from that vicinity. These sam-

FIG. 10. GREASEWOOD (proper)—*Sarcobatus vermiculatus* (Hook) Torr.

A. Appearance of a branch when not in blossom.
B. Spiny branchlet from the same.
C. Branchlet bearing cones of male flowers.
D. Cone of male flowers enlarged.
E. Branch bearing fruits.
F. Cluster of fruits enlarged.
G. Vertical section through a fruit, showing the seed with its curved embryo, (enlarged).

* This is the true *Greasewood* of the desert region east of the Sierra Nevada, and not either of the plants known under that name in the San Joaquin Valley and in Southern California.

ples show that where the Greasewood shrubs are thinly scattered and stunted in growth, the salt content per acre to the depth of three feet is about 2,400 pounds, of which over one half consists of the corrosive carbonates. Where a luxuriant growth occurs the total salts per acre vary from 38,000 to 58,500 pounds, with 18,700 pounds of salsoda and 920 to 3,680 pounds of common salt; the relative percentage of the injurious salsoda is thus invariably high. The common salt is low and the neutral glauber salt is variable. This plant therefore always indicates the presence of "black alkali."

Greasewood is distinctly a plant of the Great Basin, only reaching California in the adjacent counties of Lassen, Alpine, Mono, and northern Inyo. It is very abundant on the lower levels of Honey Lake Valley.

DWARF SAMPHIRE (*Salicornia subterminalis*, Parish, and other species of the interior); Fig. 11.

The two or three species of Dwarf Samphire which grow in the interior valleys of the State are nowhere very abundant in those portions

FIG. 11. DWARF SAMPHIRE—*Salicornia subterminalis*, Parish.

of the alkali region which we have thus far investigated. Wherever the species do occur, however, they are confined to such very strongly saline soils that they may be considered valuable indicative plants. We have as yet only one full set of samples of Dwarf Samphire soil. This shows the total salt content to amount to 441,880 pounds per acre in a depth of four feet. The neutral glauber salt amounts to 314,000 pounds, almost as much as in Tussock-grass soil; common salt up to 125,640 pounds, while the salsoda varies from 2,200 to 12,000. We may consider this plant as indicative of almost the highest percentage of common salt, glauber salt, and total salts. Like the preceding species, it indicates "white" salts in excessive amounts, and a subsoil too wet for the Australian saltbush.

Salicornia subterminalis occurs in San Diego, Riverside, Los Angeles, and Kern counties. *S. herbacea* (L.) is reported from Riverside County, and from the margin of Tehachapi Lake, Kern County. *S. mucronata* (Bigelow) occurs in San Diego County; and a fourth species is found in the Antelope Valley, Los Angeles County; near Bakersfield, Kern County; and at Byron Springs, Contra Costa County. These inland species all differ materially in habit and botanical characters from the one common in submerged salt marshes along the seashore, but all alike indicate strongly saline soils.

BUSHY SAMPHIRE (*Allenrolfea occidentalis* (Wats.) Ktze.); Fig. 12.

This plant is locally called greasewood, but as this name is much more commonly used for Sarcobatus vermiculatus, it seems best to call Allenrolfea "bushy samphire," as it closely resembles the true samphire (*Salicornia*).

Bushy Samphire usually grows in low sinks, in soil which in winter is excessively wet and in summer becomes a "dry bog." Wherever the plant grows luxuriantly the salt content is invariably high, the total salts varying from 327,000 pounds per acre, to a depth of three feet, to 494,520 pounds in four feet. The salts consist mainly of glauber and common salts (a maximum of about 275,000 pounds of each); salsoda varies from 2,360 to 4,800 pounds per acre. The percentage of common salt and total salts is higher than for any other plant investigated, and the glauber salt is almost proportionate. The areas over which this plant grows must therefore be considered as among the most hopeless of alkali lands, for although its salts are "white," submergence during winter precludes the growth of Australian saltbush.

Bushy Samphire is a common plant in alkali soils in the upper San Joaquin Valley, around Bakersfield and Delano; a few stunted bushes occur near the margin of Tulare Lake, west of Tulare, but at that point it appears to be dying out. It also occurs on the east slope of Livermore Pass, and in an alkali sink in a pocket of the hills at Byron

FIG. 12. BUSHY SAMPHIRE—*Allenrolfea occidentalis* (Wats.) Ktze.
[Called "Greasewood" in San Joaquin Valley.]

Springs, Contra Costa County. In the Death Valley region the plant appears to be very abundant, occupying an area considerably more southern than what appears to be the southerly limit of Greasewood (*Sarcobatus*).

SALTWORT (*Suaeda Torreyana*, Wats., *S. suffrutescens*, Wats., and perhaps one other species); Fig. 13.

Samples of Saltwort soil from Bakersfield, Kern County, and Byron Springs, Contra Costa County, taken to a depth of one foot and three feet respectively, show that this plant grows luxuriantly in a soil con-

FIG. 13. SALTWORT—*Suaeda Torreyana*, Wats.

taining 130,000 pounds of salts per acre in the first foot, and with 10,480 pounds of the noxious salsoda, and 39,760 pounds of common salt in three feet; while only a sparse growth is found on soils containing only 3,700 pounds of salts in three feet. It thus appears to indicate a lower percentage of salsoda than does Greasewood, but a higher percentage than Bushy Samphire. Further investigation is necessary to determine the exact relation of the different salts to the growth of the plant, and as to whether carbonates always occur in large quantity; but enough data have been gathered to show that a luxuriant growth

of Saltwort indicates a soil practically irreclaimable except at the expense of leaching.

Suaeda Torreyana occurs in abundance in certain alkali soils near Bakersfield, Kern County; in a large alkali sink near Colusa Junction, Colusa County; in Honey Lake Valley, Lassen County; Antelope Valley, Kern County; and in the vicinity of San Bernardino. Coville reports having collected it at Lone Pine, Inyo County. The closely related species, *S. suffrutescens*, only to be distinguished by an expert botanist, occurs in abundance in the alkali soils of the Mojave Desert, Death Valley, the Tulare plains, and near Bakersfield. The different species of Saltwort grow in similar habitats, and it is probable that the condition of the soil is approximately the same for each species. It thus indicates land that while not capable of bearing ordinary crops, will probably allow the Australian saltbush to succeed, at least with the aid of some gypsum.

ALKALI-HEATH (*Frankenia grandifolia campestris*, Gray); Fig. 14.

Alkali-heath is perhaps the most widely distributed of any of our California alkali plants. Its perennial, deep-rooting habit of growth, and flexible, somewhat wiry rootstock, which enables it to persist even in cultivated ground, render it a valuable plant as an alkali indicator. The salt content where Alkali-heath grows luxuriantly is invariably high, ranging from 64,000 to 282,000 pounds per acre; salsoda varies from 680 to 19,590 pounds; common salt ranges from 5,000 to 10,000 pounds. Such soils would not be benefited by the application of gypsum, as the salts are already largely in the neutral state. Of useful plants only Saltbushes and Tussock-grass are likely to flourish in such lands.

FIG. 14. ALKALI-HEATH—*Frankenia grandifolia campestris*, A. Gray.

While Alkali-heath is thus one of the most alkali-tolerant plants, it is at the same time capable of growth with a minimum of salts (total salts 3,700 pounds, salsoda 680 pounds). Where only a sparse growth of this plant occurs, therefore, the land should not be condemned until a chemical examination of the soil has been made.

Alkali-heath is found on soils of very varying physical texture and degrees of moisture; while on soils of uniform texture and moisture, but differing in chemical composition, it varies with the varying salt-content.

It has been found that Australian Saltbush (*Atriplex semibaccata*) can be successfully grown on the Colusa County "goose lands," on soil producing a medium crop of Alkali-heath; it remains to be shown whether it will do equally well on soils producing a dense and luxuriant growth of the same.

Alkali-heath is so widely distributed throughout the interior valleys of California that it would be superfluous to give a list of the localities in which it occurs. A closely related form is found in salt marshes along the coast, differing from that of the interior principally in its much broader leaves.

CRESSA (*Cressa cretica truxiliensis*, Choisy); Fig. 15.

Cressa soils show a low percentage of the noxious salsoda, but comparatively heavy total salts (161,000 to 282,000 pounds per acre.) Common salt varies from 5,760 to 20,840 pounds per acre in four feet. The maximum is lower than in the case of Alkali-heath, but Cressa seems to be much more closely restricted to strong alkali than does the former species. Cressa appears to be as widely distributed through the interior valleys of the State as Alkali-heath. It is a cosmopolitan plant, occurring, as its name indicates, on the Ionian Isles, as well as in North Africa, Syria, and in other arid countries of the world.

FIG. 15. CRESSA—*Cressa cretica truxillensis*, Choisy.

Relative Tolerance of the Different Species.

In order to determine the relative nature of the soils characterized by each of the above-named plants, Mr. Davy has prepared the following table, in which the column marked *optimum* shows, as nearly as possible with our present knowledge of the subject, the condition of the soil where each species grows in about equal luxuriance. For Saltwort and Dwarf Samphire we have not yet been able to obtain as thoroughly characteristic soil samples as could be desired, but we hope to be able to do so during the coming season.

It must be understood that the *optimum* indicates the condition under which the plant has been found at its greatest luxuriance—where it is evidently "at home"—; whereas the maximum and minimum have sometimes been obtained where the plants were more or less stunted in growth and sparingly scattered over the ground.

TABLE SHOWING MAXIMUM, OPTIMUM, AND MINIMUM OF SALTS TOLERATED BY EACH OF THE SEVERAL ALKALI PLANTS.

	Pounds Per Acre.		
	Optimum.	Maximum.	Minimum.
Total Salts.			
Bushy Samphire	494,520	494,520	135,060
Dwarf Samphires	441,880	441,880	441,880
Alkali-heath	281,960 64,300	499,040	3,720
Cressa	281,960	281,960	161,160
Saltworts	130,000	153,020	3,720
Greasewood	58,560	58,560	2,400
Tussock-grass	49,000	499,040	49,000
Carbonates (Salsoda).			
Tussock-grass	23,000	44,460	3,040
Alkali-heath	*19,590 680	19,590	680
Greasewood	18,720	18,720	1,280
Dwarf Samphires	12,120	12,120	2,200
Saltworts	10,480	12,120	1,120
Cressa	5,440	5,440	680
Bushy Samphire	4,800	4,800	1,500
Chlorids (Common salt).			
Bushy Samphire	212,080	275,160	56,800
Dwarf Samphires	125,640	125,640	125,640
Saltworts	39,760	52,900	1,040
Cressa	20,840	20,840	5,760
Alkali-heath	10,180 5,760	212,080	1,040
Tussock-grass	6,200	172,800	3,530
Greasewood	3,680	3,680	160
Sulphates (Glauber salt).			
Dwarf Samphires	314,040	314,040	314,040
Bushy Samphire	277,640	277,640	50,080
Cressa	275,520	275,520	134,880
Alkali-heath	275,520 34,530	323,200	1,560
Saltworts	44,160	104,040	1,560
Greasewood	36,160	36,160	960
Tussock-grass	19,640	323,200	19,640

* This plant grows with equal luxuriance in soils containing only 680 pounds of carbonates.

In these tables the sequence of the different plants has been arranged so that in each case the species having the highest *optimum* comes at

the head of the list. Arranged in this way the tables show that where these plants grow in luxuriance they may be considered indicative of the following conditions:

Total Salts Indicators.—The Samphires, Alkali-heath, and Cressa are all indicative of excessive total salts. Saltwort, Greasewood, and Tussock-grass indicate much lower total salt-content; indeed, the maximum of the two latter plants (Greasewood and Tussock-grass) is so low that the application of gypsum (land-plaster) would *in some cases* (e. g. the Tussock-grass lands near Bakersfield) render the soil adapted to the cultivation of Modiola and Australian Saltbush.

Salsoda Indicators.—It is noticeable that the relative position of the different species in the columns of optimum and maximum is more uniform in the salsoda table than in any other; and whether we arrange the sequence of the plants according to the optimum or to the maximum, the same relative position is maintained. This is in complete accord with what our knowledge of the effect of salsoda on vegetable life would lead us to expect; being by far the most injurious of the alkali salts, the range of tolerance is much smaller, and the limits are much more clearly defined than in the case of the other salts.

Luxuriant growths of Tussock-grass and Greasewood are invariably indicative of high percentages of carbonates, but in such cases the total salt percentage is sometimes so low that the application of gypsum (land-plaster) would render the land fit for the cultivation of Modiola or even Australian Saltbush, as noted above. It must be borne in mind, however, that where Tussock-grass grows but sparsely, the *total* salt-content may reach 499,000 pounds, an amount rendering the land utterly worthless for agricultural purposes unless the surplus salts can be removed.

Alkali-heath cannot be taken as an accurate gauge of the salsoda content, as it grows with equal luxuriance on soils containing respectively 680 and 19,590 pounds to the acre, of this salt.

The Samphires and Saltworts are relatively low down in the carbonate table, and may be taken to indicate a comparatively low percentage of "black alkali."

Neutral-Salt Indicators.—The Samphires and Saltworts head the neutral-salt tables, and are reliable indicators of excessively high percentages both of glauber salt and of common salt. Saltwort comes next to Samphire in the common-salt table, but is not quite such a good guide to the glauber salt.

Luxuriant growths of Alkali-heath, Greasewood, and Tussock-grass indicate low percentages of the neutral salts, but these plants will sometimes tolerate (in a sparse state of growth) very high percentages.